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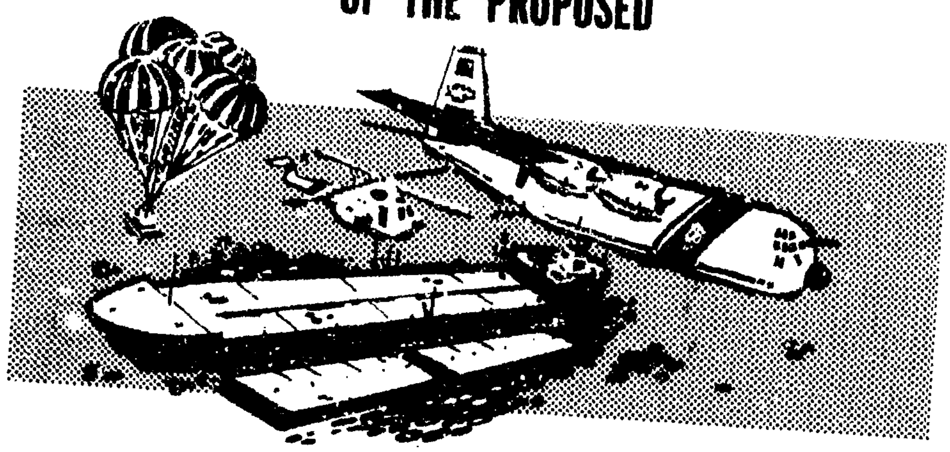

Air Deliverable Anti-Pollution Transfer System (ADAPTS)

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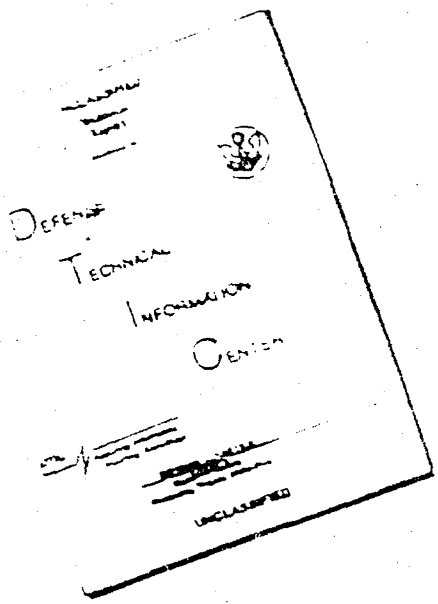

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Department of Transportation

United States Coast Guard

A Report on the Operational Capabilities of the Proposed Air Deliverable Anti-Pollution Transfer System

Volume 3: Documentation of the Mathematical Model

Plans Staff

Office of Operations

June 1971

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CHAPTER 1

INTRODUCTION

Notation

The mathematical model described herein was developed using mathematical notation and it is implemented in USASI FORTRAN (2.0)/MASTER used on the CDC-3300 computer. For this reason the model will be described using FORTRAN rules for variable and constant names and symbols. Thus NCREW, the number of C-130 air crews, is a variable symbol and not the product N*C*R*E*W. Multiplication is indicated by parentheses() or by an asterisk *; when there is no ambiguity, such as 2X, the asterisk is omitted.

[ ] Brackets are used to denote truncation to the largest integer in the expression between the brackets. Truncation in the FORTRAN model is done by using integer variable names.

{ } Braces are used to denote sets of expressions which are between the braces and are separated by commas.

() Parentheses are used to denote multiplication, grouping, or subscripts.

MIN {O,T} Means the minimum of the values in the given set.

MAX {EPKG2,BAG1} Means the maximum of the values in the given set.

The FORTRAN rule for subscripting will be followed; hence, Ai is written as A(I). Capital letters in our alphabet will be used exclusively since they are the only ones available on the CDC-3300 computer. When a letter such as ρ is preferable due to common usage, it will be called by an equivalent such as RHO. Footnotes are serially numbered and

references in the text are numbered in brackets [-] .

Description of ADAPTS

The Air Deliverable Anti-Pollution Transfer System (ADAPTS) includes aircraft, aircraft ground equipment, large moveable Diesel driven pumps, hoses, collapsible tanks, and men with their supplies of food, water, etc. A hypothetical incident for use of this system would be: a tanker loses propulsion power during a storm when approaching New Jersey from Venezuela and is driven aground on a sandy beach. There is no damage but no other ship can approach it due to shoals. Barges are available but the gathering and towing of barges to the tanker from New York City and Wilmington, Delaware, will require five to seven days and at least two more days will be needed to lighten the tanker sufficiently so it can be floated. The Coast Guard and other agencies are notified. The Coast Guard decides to use ADAPTS after evaluating the situation including the chances for another storm.

The deployment of the system begins by notifying Elizabeth City Air Station (ECAS), Cape May Air Station (CMAS), and Brooklyn Air Station (BAS). BAS is nearest to the scene and it is equipped with the largest helicopters (HH-3F's) the Coast Guard uses; BAS immediately loads a pump and Diesel package into a cargo sling and the ready HH-3F brings it to the scene of the grounding. A crew is called to man a second HH-3F within an hour. At CMAS the situation differs; this air station has only HH-52A's for helicopters and unlike the HH-3F they can not carry a heavy load any distance. CMAS remains on alert to send its helicopters for work at the

scene in eight hours (after all heavy delivery is completed and when the crews of the HH3F's must rest). At ECAS the ready C-130 begins loading a parachute equipped pump and Diesel set as well as a parachute equipped collapsed rubber tank called a bag package. A second and third C-130 are being readied by installing a rail system (the loaded equipment is on pallets that will slide over these rails when loading and when parachuting the equipment) and more C-130 crews are called to be ready by the time these C-130's are ready. After the first C-130 is loaded, four salvage teams of four men each board the plane and the plane flies to BAS. There the salvage teams board HH-3F's and are brought to the scene while the C-130 airborne again, flies to the scene and prepares to parachute the equipment. When the first salvage team is ready and a helicopter is waiting the equipment is dropped from the C-130; automatically anchors when it enters the water except for the A-frame hauling and lifting device (HLD) which is buoyant and free floating. The helicopter grapples for the HLD and brings it to the salvage team which assembles the HLD while the helicopter attaches lines to the anchored equipment and brings either the equipment or the lines to the salvage team depending upon the type of helicopter, the distances, and the weather. The salvage team finishes hauling the equipment to and on the tanker and then hauls in the end of the hose from the collapsed bag. The equipment is assembled and the pumping, at a maximum rate of 1000 U. S. gallons per minute per pump, begins into the rubber bag. The aircraft continue bringing equipment and bags until all that are needed are at the scene. In spite of the distances involved, enough bags can be delivered in 24 hours to lighten

the tanker. This is the time limit desired. After 15 bags have been filled and moved to a safe anchorage, an attempt to pull the tanker succeeds and the tanker is towed to New York. A Coast Guard Buoy Tender which was sent to the scene picks up the seven unused bags and brings them to New York. Coast- Guard and commerical tugs tow the full bags slowly to Bayonne, New Jersey, where they are emptied into storage tanks or tank barges. All the equipment is eventually brought to BAS where it is loaded On C-130's for return to ECAS for repair and repackaging.

The most important aspect of the use of ADAPTS is illustrated by this example. Powerful equipment must be brought from its storage to the distressed tanker, in time to prevent an oil spill. A tanker, aground or drifting out of control, is at the mercy of weather. The measure of effectiveness for this model, what can be done in 24 hours, was picked with weather in mind. Some tankers become distressed due to rough weather; they have five days on the average before rough weather occurs again. It is during that five day period that salvage can be attempted. Some tankers such as the TORREY CANYON become distressed independently of weather. For those tankers, the ones that become distressed during good weather will have on the average two days until a storm arrives and the ones that become distressed during rough weather will have nearly five days until another storm arrives. A small tanker in distress near ECAS can be emptied by ADAPTS in 24 hours while at the other extreme a supertanker in distress in the Florida Strait will require many days of off loading to be emptied. The model solves for what can be done in 24 hours by ADAPTS in weather up to 40 knot winds, 12 foot seas, and 1000 foot ceiling. An evaluation of the weather forecasted,

the size of the tanker, its distress, and Coast Guard resources currently available is needed to determine what resources to use and what additional resources must be obtained. Thus this mathematical model is an aid in the decision process.

The hypothetical incident gives a preliminary description of the system. For the purpose of detailed description, we will consider it to be comprised of four subsystems:

a. ECAS with C-130 aircraft. Other aircraft there are not used in ADAPTS so they are ignored.

b. Two other air stations (HP1 nearest to the incident scene and HP2 next nearest) with helicopters. Other aircraft there are incidental; they are not used in ADAPTS.

c. The aircraft delivered pumps at ECAS, HP1, and HP2 and the bags at ECAS.

d. The salvage teams with life support equipment.

ECAS Aircraft

The Coast Guard Air Station at Elizabeth City, North Carolina is centrally located on the east coast of the United States. Because of a reorganization of aircraft deployment several years ago, it is currently the only Coast Guard air station in the East with C-130's. With little effort it can be doubled to two sources of C-130's, but because of the distances involved between C-130 equipped air stations, they are independent for all practical purposes. This model, based upon one C-130 equipped air station, is valid for San Francisco Air Station and other C-130 equipped air stations although ECAS is the only one mentioned in this paper. Table

1 presents the standardized operating parameters for the three types of Coast Guard aircraft used by ADAPTS; in it are included the aircraft used by ADAPTS and excluded from it are the other types operated by the Coast Guard. Up to 15 C-130's and loaders are allowed in the model although this number is not possible from Coast Guard resources. This high allowance permits "what if" questions. The number of loaders, L, is constrained to be less than or equal to the number of C-130's, N, since only one 25K loader[1] can be used by a C-130 at a time.

Helicopter Air Stations

The air stations nearest and next nearest to the scene of the distress are the only two air stations considered in this model for helicopter resources. The others will almost always be far beyond the range of helicopter operations and in some instances such as scenes of distress northeast of Portland, Maine, the nearest air station (CCAS) is at or beyond the limit of loaded HH-3F's. In those instances, the HH-3F's can work at the scene, but the salvage teams must be delivered by other means. In such an instance this model is inapplicable. The air station nearest to the scene is called HP1 in the model and the next nearest to the scene is called HP2. Whenever a distance is placed into the model that exceeds the capability of the helicopter the helicopter is removed from the model, and if no helicopters are left at HP1, the model prints this fact and terminates solving the problem. If the mathematical model is solved manually, the total flight time of an HH-3F must

[1]This paper use the 25,000 pound capacity loading machine as a standard. It is described in the model only by the total time required to load a C-130, D. Change the value of D if other loaders are used.

not exceed 182 minutes when it is loaded with a complete pump and Diesel set and the total flight time of an HH-52A must not exceed 120 minutes when it is carrying a third of a pump and Diesel set. These times are derived from the weights, distances, and the parameters in Table 1.

Pumps and Bags

The equipment especially developed for ADAPTS consists of the pump and Diesel sets (hereafter called pumps when at the scene and E pkgs when packaged for delivery) and the bags (hereafter called bags when in the water at the scene or when filled and B pkgs when packaged for delivery).

A C-130 delivery E pkg consists of:

a. A small rubber tank containing 55 gallons of Diesel fuel,

b. A Diesel engine - hydraulic pump set that is packaged to float,

c. A submersible hydraulic motor in a common housing with a crude oil pump that is packaged with hoses to float,

d. A hauling and lifting device which is an A-frame with a manual winch and tie-downs, and

e. Packaging material including parachutes, pallet, package opening equipment, lines, floats, and an anchor.

The pump set is capable of pumping 1000 gallons of medium weight crude oil per minute. When a E pkg is dropped out of the tail of a C-130, the parachutes open automatically and a timer is started. Just before the E pkg hits the water it begins to open and the HLD falls out. It floats free. When the E pkg is in the water, the parachutes are cut off and an anchor is dropped. It is now ready for hauling to the tanker.

A helicopter delivery E pkg is the same as above except that parachutes and the anchor are unnecessary; also the packaging is lighter since it will not be dropped. If an HH-52A is used (only for short distances), the components of an E pkg are delivered separately.

A B pkg consists of:

a. A folded rubber bag capable of holding 500 tons (125,000 U. S. gallons) of crude oil and a hose,

b. Flotation tubes and inflater, and

c. Packaging material including parachutes, pallet, package opening equipment and an anchor.

When a B pkg is dropped out of the tail of a C-130, the parachutes open automatically. When the B pkg hits the water, the parachutes are cut off and an anchor is dropped. After a time delay the package opens and the water sensitive flotation inflater releases nitrogen gas into the flotation tubes. The hose floats out (one end is plugged and the other end is fastened to the bag filling connection). The flotation tubes straighten the bag so it floats ready for filling.

The Salvage Team

The salvage team is comprised of enough men to run the pumps and fill the bags at the scene for at least 24 hours. They are equipped with a radio, emergency lighting, bedding, and food. Roughly four men are needed per pump for around the clock operation but this number may be changed when weather and season dictate. It is convenient to divide the full salvage team into four man salvage teams for purposes of helicopter load capacity. This amount of men can be carried by an HH-52A to the

same distance it can carry a third of an E pkg. A salvage team means a four man team hereafter.

TABLE 1

AIRCRAFT PARAMETERS

Plane	Speed in Knots Out	Back	Carrying Capacity Pounds	Reserve Fuel Pounds	Mean Refueling Time in Minutes	Average Fuel Consumption Pounds/Hour
HH-52A	85	95	2,000 F+C	200	20	400
HH-3F	115	125	7,000 F+C	600	30	1,100
C-130	270	290	17,000 C @ 45,000 F	4,000	40	4,000

F = fuel; C = passengers and cargo

CHAPTER 2

DEVELOPMENT OF THE MATHEMATICAL MODEL

The desired result of the mathematical model is to find the maximum number of bags that can be filled in 24 hours subject to the numbers of C-130's, C-130 air crews, C-130 loaders, helicopters, and E pkgs. This is a model for measuring the operational results that can be attained with available resources. Four equations will be derived to describe these resource constraints. The first one includes C-130's and C-130 loaders; it describes the number of plane loads that can be delivered in time for the bags to be filled within the 24 hour limit when E pkgs are not constraining. The second equation uses C130's only and it yields the maximum possible number of tanks that can be delivered and filled in 24 hours if the other variables are not constraining. Although it is of little use in an operational model, it is included since it provides a comparison for the measuring of the effective use of the utmost costly resource, the C-130 airplane. The third equation includes helicopters and E pkgs as variables. It describes the time needed to deliver E pkgs to the scene and the number of tanks that can be filled by them within the 24 hour limit with C-130 aircraft and loaders not constraining. The fourth equation includes C-130's, C-130 air crews, and C-130 loaders as variables. It describes the number of bags that can be delivered within the 24 hour limit. When E pkgs are not constraining this can be converted to the number of tanks that can be filled in 24 hours

If the number of tanks that can be filled in 24 hours is known, the number of C-130 trips needed to deliver that number of tanks is

$$X = \frac{1}{2}\left(Z + \sum_{I=1}^{N} P(I)\right)$$

This transformation of variables and its inverse,

$$Z = 2X\sum_{I=1}^{N} P(I)$$

are used extensively.

A variable named CHECK1 is introduced as an input so that the user of the model may choose to or not to check that variables in the input card deck do not violate the allowable range over which they are defined for this mathematical model. CHECK1 also checks the helicopters by type to see if they can carry an E pkg to the scene (distance is the only consideration checked). To use CHECK1, input a value of 1.0 on the appropriate card.

Loader Equation

The amount of bags that can be delivered and filled in 24 hours is subject to the number of C-130 loaders. The loaders are considered as servers in a queueing problem and the C-130's as the arriving clients; the queue that results is a deterministic queue with the facility utilization factor dependent upon both the number of servers and the number of clients[2]:

$$P = \frac{\lambda_n}{\mu s} = \frac{\text{average number of arrivals per minute}}{\text{average number of loadings per minute}}$$

The expected time between arrivals (the reciprocal of average arrival rate) is $1/\lambda_1$, = B+C for each C-130. Thus for N C-130's it is $1/\lambda_n = \frac{B+C}{N}$ which is $\lambda n = \frac{N}{B+C}$ arrivals per minute. The expected service time per loader is $1/\mu$ = D. The number of servers, s, is the number of C130 loaders, L. Thus the facility utilization factor is RHO = $\frac{ND}{(B+C)L}$. It is the fraction of time that the loaders are busy.

[2]See Hillier & Lieberman. Introduction to Operations Research. On page 290 this formula is defined.

The time the loaders have available for loading is described by the maximum possible time during the 24 hour period during which C-130's are available for loading. The first loader can begin loading the first C-130 when it ends its standby, A(1). Similarly the Lth loader can begin loading only when the Lth C-130 ends its standby, A(L). This stems from the definition $A(I) \leq A(I+1)$ for all C-130's. Other factors that reduce the available loading time are measured from the end of the 24 hour period to the time that the last load, which can be delivered in time for filling, has been loaded. So, for the Ith loader, the time available for loading is 1440-(B-D)-U-R-A(I) minutes and for all the loaders it is

$$(1440-B+D-U-R)L-\sum_{I=1}^{L} A(I)$$

The used loading time is the product of the facility utilization factor times the total available loading time with the total available loading time representing the maximum used loading time possible. Therefore used loading time is

$$\min\left\{1, \frac{ND}{(B+C)L}\right\}\left((1440-B+D-U-R)L-\sum_{I=1}^{L} A(I)\right)$$

This number, when divided by the loading rate and truncated, yields the constrained number of C-130 trips, IX1:

$$IX1 = \left[\frac{\min\left\{1, \frac{ND}{(B+C)L}\right\}\left((1440-B+D-U-R)L-\sum_{I=1}^{L} A(I)\right)}{D}\right]$$

Note that $1 \leq L \leq N$. If either L or N is equal to zero, there can be no bags delivered or filled. It is senseless to consider $L > N$. Any loaders more than C-130's simply will not be used. IX1 is converted to the constrained number of bags filled by the transformation: IX1T = 2(IX1)-

$$\sum_{I=1}^{N} P(I)$$

Also when RHO > 1, the C-130's wait. Since N is finite, the queue length can not exceed N-L, the number of C-130's not in service. In steady state the expected time between arrivals becomes $\frac{B+C+delays}{N}$ where W, the waiting time is the delay:

W = 0 for RHO < 1 and

$W = \frac{ND}{L} - B - C$ for RHO=1. When W is considered, one can deduce that the facility utilization attains 1 as its maximum.

The C-130 Equation

As stated earlier in this chapter, this equation is provided for gaging the maximum number of C-130 trips and the resulting amount of bags that can be filled in 24 hours. It is not used in the present model although it was the first equation derived in modeling the operational deployment of ADAPTS. It led to the derivation of the fourth equation for IX5, the number C-130 trips that can be made (so that bags delivered can be filled within the 24 hour limit) with given number of C-130's, C-130 loaders, and C-130 air crews. An intermediate equation labeled IX4 will not be described but since its name appears in several computer runs, its name was not reused to avoid confusion.

Note that 1440-R-U minutes are available for a C-130 to deliver packages in 24 hours and that the C-130 time used is A(I)+B*X(I)+C(X(I)-1) where X(I) is the number of trips made by the Ith C-130. Thus for the Ith C-130, 1440-R-U ≥ A(I)+B*X(I)+C(X(I)-1). This is an inequality because there may be a fraction of a trip possible in the time available; C(X(I)-1) indicates that for the purposes of filling tanks the last return trip is not considered,

so one return trip is subtracted. After solving for X(I) and truncating the possible fraction of a trip, one has: $X(I) = \left[\frac{1440+C-R-U-A(I)}{B+C}\right]$

Next sum over N C130's to have:

$$IX2 = \sum_{I=1}^{N} \left[\frac{1440+C-R-U-A(I)}{B+C}\right]$$

This formula gives the maximum number of C-130 trips possible when there are no waits for loaders and there are enough air crews for the 24 hour period. Multiply by two and subtract the number of C-130 delivered pumps to find the number of C-130 delivered bags.

The Equipment Package Equation

The number of bags that can be filled by the pumps within the 24 hour limit is a function of the number of pumps and when they are delivered. There are two ways by which the pumps can be delivered; by helicopter and by C-130.

When pumps are delivered by C-130's, the following restrictions apply:

a. only one pump is in a plane load,

b. the pump is dropped first,

c. the first pump delivered by a C-130 is delivered on its first trip, and

d. the remaining pumps are delivered in consecutive trips.

These restrictions did not apply to the network analysis of ADAPTS, the first two were required to construct the simulation model, and all were necessary to derive this equation.

When pumps are delivered by helicopter, the number and type of heli-

copters are important. Several simplifing assumptions were made. The first is that zero, one, or two pumps may be prepositioned at either or both helicopter equipped air stations. Analysis of the simulation results have shown that, even with the faster and more powerful HH-3F, the third and later pumps (when allowed) are delivered so late that they are marginal in results. Another assumption is that only one helicopter from HP2 can be used and that if it is used it is an HH-3F. The assumption of one type only comes from the fact that HP2, being farther from the scene, will normally be beyond the range that an HH-52A can deliver a pump. HP1 has one or two helicopters of either type but the types may not be mixed, they are mutually exclusive in this equation to avoid the combination of pump and helicopter delivery schedules that could arise. The two types of helicopters would be drawing from the same group of pumps so that pumps delivered have to be subtracted from the pumps available for delivery by the other type. It will become evident in the remainder of this section that, even with these simplifing assumptions, this is the largest and most difficult equation.

A final assumption is that the HH-52A helicopter can be used to deliver a pump in thirds; that is, an E pkg which is constructed in three modules of nearly equal weight. There is serious doubt that this can be done and still have a pump with a rated output of 1000 gallons per minute. If it can not, the portion of the equation that describes such delivery can be removed without harm.

1. The Ith C-130 delivers a pump on its first trip and, after E1 minutes, this pump is ready for use. Thus from the A(I)+E1+B minute to the 1440th minute, it is available for pumping; this is 1440-A(I)-B-E1 minutes of pumping time. The C-130 makes a round trip of B+C minutes

before it delivers the next pump; hence, the next pump has 1440-A(I)-2*B-C-E1 minutes of pumping time. Similarly the P(I)th pump delivered by the Ith C-130 has 1440-A(I)-P(I)*B-(P(I)-1)*C-E1 minutes of pumping time available. The total pumping time available from pumps delivered by the Ith C-130 is: $(1440-A(I)-E1)P(I)-B\sum_{z=1}^{P(I)} z - C\sum_{z=1}^{P(I)}(z-1)$ which equals[3]

$$(1440+C-A(I)-E1)P(I)-\left(\frac{B+C}{2}\right)\left(P(I)^2+P(I)\right)$$

When this expression is divided by R, the pumping rate, and the result is truncated, the result is the number of bags that can be filled by the pumps delivered by the Ith C-130. It is labeled IDUM in the FORTRAN model. When P(I)=0, the result is zero. Note that two off-setting assumptions are made:

a. This C-130 suffers no waits and

b. the summation can be made before dividing and truncating.

The errors introduced by these assumptions are off-setting so that the net error is very small. Under some circumstances when the 24 hour limit is impossible, IDUM can be negative in this formula. These circumstances occur when A(I) is close to 24 hours and B+C, the round trip time is large. To prevent negative values, use max $\left\{0, \text{IDUM}\right\}$ when summing over all C-130's to find the number of bags that can be filled by these pumps.

The number of bags that can be filled by helicopter delivered pumps will be derived for HP1 using HH-3F's, HP2 using an HH-3F, and HP1 using HH-52A's. The two types of helicopters at HP1 deliver the same pumps so they are made mutually exclusive to prevent erroneous results. If HH-3F's are available, then HH-52A's are not used since they are very limited in

[3] See Jolley, L. B. W. Summation of [illegible]. New York City: Dover 1961. The formulae on pages 2 and 3 are used to solve for the above closed form.

comparison. The model is written to set $Q52=0$ if $Q1 \neq 0$.

2. The number of bags that can be filled by pumps delivered by HH-3F's from HP1 is derived by noting that Q1 and M1 are integers each limited in value to 0, 1, or 2. This allows the use of logical IF statements and separate expressions for the number of bags filled with different resources.

Define $G = A(1)+B+2*H1$ as a constant equal to the time the first helicopter spends waiting for a salvage team, delivering it, and returning to HP1 to pick up an E pkg. Note that E2+H+G is the time the first E pkg delivered by an HH3F is ready but that bags may not be available for filling until A(1)+B+U. Thus the available pumping time for the fitst E pkg is $1440-\max\left\{E2+H1+G, A(1)+B+U\right\}$ when M1=1 or 2 and Q1=1 or 2 and it is zero when either M1=0 or Q1=0. Since $G = A(1)+B+2*H1$, the formula can be simplified. Divide by R and truncate to find the number of bags that can be filled by the first pump from HP1 during the 24 hour period.

$$\left[\frac{(1440-A(1)-B-E2-3H1)}{R}\right]$$

If two HH-3F's are at HP1 and there are two E pkgs there, the next E pkg is ready at E2+H1+F when the first salvage team is there and bags are ready (other salvage teams are delivered after this E pkg in the chosen strategy). Therefore when M1=2 and Q1=2, the available pumping time from the second pump is:

$$1440-\max\left\{E2+H1+F,\ A(1)+B+H1+E2, A(1)+B+U\right\}$$

where E2+H1+F is the time to have pump ready when helicopter delivers it only, where A(1)+B+H1+E2 is the time to have pump ready when helicopter delivers a salvage team first, and where A(1)+B+U is the time that a bag becomes available for filling. When this is divided by R and truncated, the results is the number of bags that can be filled by the second pump

if it was delivered by the second HH-3F. It is constrained to be greater than or equal to zero; it can be added to the expression for the first pump, but if there is only one HH-3F at HP1 and M1 is equal to two, the next E pkg is ready at:

$$G+2H1+(S-1)2H1+H1+E2 = E2+G+(2S+1)H1 \text{ since:}$$

G = Time helicopter becomes available to deliver E pkg

2H1 = time to deliver remaining salvage teams

H1 = time to deliver this E pkg

E2 = time to set up this E pkg

Therefore the available pumping time from the second pump from HP1 is 1440-E2-G-(2S+1)H1 when there is only one HH-3F. The desired expression is selected by using logical IF statements to choose among the possible values of M1 and Q1. The above expression, divided by R and truncated is the number of bags that can be filled by the second pump in 24 hours if there is only one HH-3F at HP1. Thus the number of bags that can be filled by pumps delivered by HH-3F from HP1 is equal to:

$$\left[\frac{(1440-A(1)-B-E2-3H1)}{R}\right] \text{ for the first pump plus either}$$

$$\left[\frac{(1440-\max\{E2+H1+F, A(1)+B+H1+E2, A(1)+B+U\})}{R}\right]$$

for the second pump and two helos or

$$\left[\frac{(1440-E2-G-(2S+1)H1)}{R}\right] \text{ for the second pump and one helo.}$$

3. The number of bags that can be filled by pumps delivered by HH-52A's (in lieu of HH-3F's) from HP1 is derived in a similar manner. The time necessary to deliver the pump is:

2H52 = round trip time to delever salvage team

H52 = 1/3 pump delivered

H52 = time of trip back to HP1

H52 = 2nd third delivered

H52 = time of trip back to HP1

H52 = last third of pump delivered

7H52 = total for the first pump

H52 = time of trip back to HP1

2(S-1)H52 = time of round trips to deliver the remaining salvage teams

5H52 = time to deliver the second pump

This totals to (2S+11)H52 for the second pump.

By a reasoning process similar to the derivation for HP1 equipped with HH-3F's we arrive at the number of bags that can be filled by HH-52A delivered pumps (from HP1 only). It is equal to zero if either there are no pumps or no helicopters, it is constrained to be greater than or equal to zero when M1 and Q52 are equal to either one or two. The expression is:

$$\max\left\{0, \left[\frac{1440-\max\left\{E2+E+11H52-4Q52*H52, A(1)+B+U\right\}}{R}\right]\right\}$$

for the first pump and

$$\max\left\{0, \left[\frac{1440-E2-F-25H52+9Q52*H52-(3-Q52)*S*H52}{R}\right]\right\}$$

for the second pump. The model bypasses these expressions whenever Q1 is greater than zero since delivery by HH-52A is not done when HH-3F's are available.

4. The last portion of the equipment package equation is the number of bags that can be filled by pumps delivered by an HH-3F from HP2. As stated earlier, the possibility of using HH-52A's from HP2 is very remote due to the greater distance and the lesser capability of the HH-52A.

This part of the model is constructed with one HH-3F at HP2. It could be changed to allow two but it is doubtful that the second would be used since it would be on standby during the time the first pump from HP2 is delivered. It represents a resource that would have marginal effect so for simplification of the formula, it was not included. Since Q2 equals zero or one only, a logical IF statement is used to bypass this expression when there are no helicopters.

The first from HP2 is ready for use at:

max $\left\{ E2+F+H2, A(1)+B+U \right\}$;hence, the resulting expression for the number of bags filled is:

$$\max \left\{ 0, \left[\frac{1440 - \max \left\{ E2+F+H2, A(1)+B+U \right\}}{R} \right] \right\}$$

For M2=2, the second pump is set up at EPKG7=E2+F+3H2 but the second bag is not ready until: U+ min $\Big\{$ second trip by the first C-130, first trip by second C130 if N 2, first trip by first C-130 if P(1)=0 $\Big\}$.

The second trip by the first C-130 takes A(1)+2B+C minutes. The first trip by the second C-130, when there is a second C-130, takes A(2)+B minutes. A penalty is assigned to this time to increase it beyond the second trip time of the first C-130 when there is only one C-130. The first trip by the first C-130 is considered only if it delivers no pumps, that is if P(1)=0. This means that a second bag was delivered and is available for use. The resulting expression for the bags filled by the second pump is

$$\max \left\{ 0, \left[\frac{1440 - \max \left\{ EPKG7, \min \left\{ BAG2, TBAG2 \right\} \right\}}{R} \right] \right\}$$

where EPKG7 = E2+F+3*H2

BAG2 = A(1)+B+U if P(1)=0

= A(1)+2B+C+U if P(1)≠0

TBAG2 = BAG2+1 if N=1

A(2)+B+U if N≠1

Thus the number of bags that can be filled by pumps at the scene is the sum of the number of bags that can be filled by

a. the pumps delivered by C-130's,

b. the pumps delivered by HH-3F's
   or delivered by HH-52A from HP1, plus

c. the pumps delivered by an HH-3F from HP2.

The C-130 System Equation

The number of C-130 trips that can be made to deliver bags in time for them to be filled in 24 hours is IX5, the dependent variable in this equation. By using the transformation,

$$IX5T = 2*IX5-\sum_{I=1}^{N} P(I)$$, we have the number of bags that can be filled in 24 hours. IX5 is the result when the independent variables, the input, are the number of C-130 loaders, L, the number of C-130's, N, and the number of C-130 air crews, NCREW.

In this equation there are many restricting assumptions. They will be discussed as they arise. The first assumption is that the number of trips taken by a C-130 is the minimum of two values; the first is the number of trips that it can take due to the endurance of the air crews assigned to that C-130 and the second is the number of trips that it can take due to the time available to that C-130 before 24 hours are finished.

The formula is derived by pairing the first L C-130's to the L loaders. Then the next L C-130's are paired to the L loaders.. For example when L = 3 and N = 5, the first loader serves the first and fourth C-130's. There are several assumptions inherent in this pairing. The first is that the second

group of C-130's causes no delays to the first; that is, any delay suffered is absorbed by the second group. Actually both groups suffer delays and this assumption assigns all the delays to the second group. Since there is no attempt made to measure the delays of each C-130, this assumption does not induce measureable changes. The next assumption is that after an initial delay equal to the loading of the first C-130, the L+1st C-130 loads during the time the first C-130 is away on a trip. The initial delay serves to phase the aircraft, this assumption holds whenever $2D \leq B+C$ (distance from ECAS to the scene is greater than 165 miles when loading time is 90 minutes). It causes some overestimation of the number of trips whenever the distance is less than 100 miles; however, this is first of all a remote possibility and secondly this is a distance for which the actually available resources in helicopters becomes constraining for IX3T. Hence little error was noted in the verification.

The last major assumption was that, when $N > 2L$, only the first 2L C-130's need to be considered and that the remaining C-130 aircraft may be ignored. This assumption holds for the shorter distances since there is not enough time during C-130 trips for two loadings to be accomplished before the airborne C-130 returns. The third C-130 for a given loader always causes a long wait; that is, for each server, there is always one in service and waiting. What is a shorter distance? For $N > 2L$, three loadings must occur within the time of a round trip - this means $3D \leq B+C$. This means that this assumption causes no error under 375 miles when loading time is 90 minutes To the north of ECAS this distance is nearly the limit at which two helicopter equipped air stations can be used. For all practical purposes this means that IX3T becomes constraining. To the south of ECAS the same constraint occurs at present, and in several years, there will be additional C-130's at Miami Air Station so that distance will no longer be germane.

It can be seen that with the distances involved and with the other factors of equipment and locations, these assumptions cause little trouble and allow this equation to be derived. For each of the first L C-130's the time available for each to make round trips is the minimum of 60*CEND*NC(I) and 1440+C-R-U-A(I). The first is the air crew time available and the second is the C-130 time available in 24 hours; since both must be available, the lesser value is used. It is divided by B+C and truncated to yield the number of trips made be that C-130. For the next L C-130's the first number is unchanged and the second becomes 1440+C-D-R-U-A(I) to incorporate the initial delay. The lesser value is then divided by B+C and truncated. The trips by each C-130 are summed to form IX5. Thus IX5 equals

$$\sum_{I=1}^{\min\{L,N\}} \left[\frac{\min\{60*CEND*NC(I),\, 1440+C-R-U-A(I)\}}{B+C} \right] +$$

$$\sum_{I=L+1}^{\min\{2L,\, N\}} \left[\frac{\min\{60*CEND*NC(I),\, 1440+C-D-R-U-A(I)\}}{B+C} \right]$$

Should the need arise, a third summation could be derived for $2L < N < 3L$; however, since this summation would be effective only for distances greater than 375 miles and since these distance occur mainly at the limit of effective helicopter availability, it will not be done.

Because of the many assumptions taken in deriving this constraint equation over thirty verification comparisons were made between the mathematical model and the simulation model. The differences caused by the above assumptions are not significant until the distance, DM, is less than 100 miles or greater than 650 miles. Both conditions are rare for the East Coast.

Finally, the model selects the most constraining set of constraints as described by the equations for IX1T, IX3T, and IX5T as the maximum number of bags that can be filled in 24 hours.

CHAPTER 3

VERIFICATION OF THE MATHEMATICAL MODEL

Verification of the mathematical model could not be accomplished by comparison of results with actual field tests of ADAPTS since the system is still in prototype development. Verification was accomplished by proceeding in a three step comparison.

The first step was to assign numbers to each of the procedures and events that occur in the operational deployment of ADAPTS. This was done by observing the field tests of the prototype equipment and timing the events as they occurred. The results of each test were compared and the duration of each event was evaluated with the following criteria:

a. was the work done in a knowledgeable manner free of hesitation and false starts,

b. were any of the delays that occurred strictly attributable to the nature of the test, that is, generated by the test,

c. if this event was repeated many times over, would the speed of the work increase,

d. is there a faster way of doing this, and

e. would this event occur in the same way during an actual operational deployment?

Since ADAPTS involves the use of aircraft, portable salvage equipment, and people, the use of an aviator, a shipboard engineer of a rescue ship, the executive officer of a rescue ship, and a civil engineer to evaluate the events was appropriate. The resulting times for accomplishing the events were combined to form the time required to perform tasks[4]. Each task was so defined

[4]Not all of these times [illegible] in. The times pertinent to [illegible] are given in Appendix A as th[illegible]lues of the defined constants.

that it could be placed in a network for critical path analysis, critical path analysis followed using the ICES-Project 1 package for computer analysis of the network. The method was tedious but it did progress well when working with small quantities of resources. The results were easily verified as both reasonable and optimal for the resources and strategies. But as more resources were added, the PERT-CPM networks became too cumbersome to form.

The second step of the verification was to construct a discrete simulation model that allowed a wide range of resources and printed enough data so that it could be compared with the results of the network analysis. GPSS was selected for the simulation language; it proved well suited for the task. Many assumptions were required to complete the simulation model, (see Volume 2 of this report) they were of several classes:

a. first the practical number of resources that could be examined by the model; e.g. a matrix column was needed per C-130 to log flight completions.

b. second that certain strategies (order in which tasks were done) were best. For example the strategy that was optional for one helicopter was to:

1. deliver a salvage team,
2. work at scene as long as needed,
3. deliver one prepositioned helicopter delivery E pkg,
4. work at the scene as long as needed,
5. deliver remaining salvage teams with work at the scene during trips allowed,
6. deliver remaining E pkgs with work at the scene during trips allowed, and
7. make trips solely for working at the scene.

This strategy was assumed to be best for the first helicopter when more than one helicopter is available. Whenever possible, the choice of strategy was verified by network analysis.

c. third, the printed results need not cover all data generated. This did not prove satisfactory and the printed output was doubled.

The assumptions used in the development of the simulation were not compatable with some of the networks that had been investigated; however, for four of the networks the assumptions and inputs were directly comparable (see Table 2) These four direct comparisons showed the validity of the simulation model. Several relative comparisons were also made. These were comparisons with the same resources where the strategy used in the simulation model resembled the strategy used in the PERT-CPM analysis. They showed results differing by one or two bags filled in 24 hours. These comparisons showed that the strategies used in the simuation model were generally better than or equal to the strategies used in the networks. This tended to prove the assumptions on strategies.

The final step of the verification was to make comparisons between the results of the simulation model and the mathematical model when identical resources and strategies were used as inputs. For thirty different resources and location combinations, duplicate computer runs were made. There was only one measurement of results used for this comparison and it was the number of bags filled in 24 hours. The absolute value of the differences between the results of the two models averaged at 1.333 bags; this represents a 4.5 percent error which is acceptable for planning purposes. The graphed results of the simulation and the mathematical models produced nearly identical curves (see Figure 1 for example). This figure also illustrates that the number of bags filled does not vary linearly with distance.

These facts show that the mathematical model reproduces the results that an actual operational deployment of ADAPTS would give. The mathematical model, however, because of constraints built into it, can not reproduce the results of [illegible] deployment of ADAPTS. It requires that all the E [illegible] to be de-

TABLE 2

SIMULATION MODEL VERIFICATION[1]

Event	Percent Difference between methods			
	Run 1	Run 2	Run 3	Run 4
Last E pkg set up	3.34	0.16	1.52	1.02
First C130 returns to ECAS	0.84	0.84	0.84	0.84
First bag filled	3.95	1.96	1.96	3.22
Second bag filled	0.36	0.17	0.17	0.17
Third bag filled	0.74	0.14	0.14	zero
Fourth bag filled	0.59	1.21	0.14	zero
Fifth bag filled	0.63	0.12	0.12	0.39
Tenth bag filled	0.38	0.76	0.08	0.14
Twelfth bag filled	0.34	0.68	0.08	0.24
Twentieth bag filled	0.24	0.47		

[1]This is condensed from volume 2 of this report.

livered by a C-130 be delivered one per trip, starting with the first trip, without skipping a trip until the last E pkg has been delivered. The simulation model allows gaps of bag-only trips before all E pkgs have been delivered but it still limits the C-130 to carrying one E pkg per trip. The PERT-CM analysis allowed any combination. The simulation model allows the helicopter at HP2 to be an HH-52A or an HH-3F but the mathematical model allows an HH-3F only. The network, being less restricting, allowed any type of helicopter. A final example of difference is that the network and simulation model output lists when each tank would be filled while the mathematical model gives only how many tanks can be filled in 24 hours.

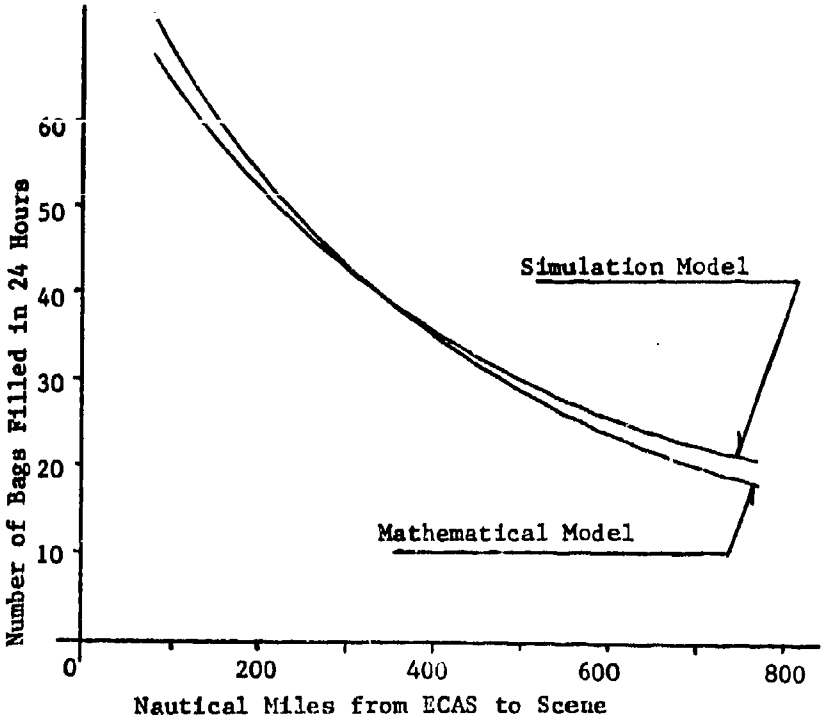

Figure 1 Mathematical Model Compared With Simulation Model[1].

[1]Identical resources and similar delivery strategies:

<u>Resources</u>

5 C-130's at ECAS with rails installed on the first
10 C-130 air crews each with 12 hour endurance
A manifold and an HLD in each E pkg
-4A rails used
6 Salvage Teams at ECAS
4 E pkg's at ECAS, 2 at HP1, and 2 at HP2
5 C-130 loaders rated at 25,000 pounds
2 HH-3F helicopters at HP1 and 1 at HP2

<u>Strategies</u>

Only 2 packages per trip; either 2 bags or 1 bag and 1 E pkg in which case the E pkg is dropped first.

E pkg deliver:

C-130 #	Trip Number Simulation	Mathematical Model
1	1,3	1
2	1	1,2
3	-	-
4	2	1
5	-	-

Model Control for Continued Verification

Since this model is based upon a prototype of ADAPTS, controls are necessary. First, any differences between the prototype system and the final system must be determined and then the model must be corrected. Second, actual deployment of ADAPTS will help further define the time needed to accomplish the tasks involved and these time values should be used in lieu of the values given in Appendix B. An example of the former would be a radical change in the size of a tank so that three T pkgs could be carried by a C-130 instead of two. The formula $Z = 2X - \sum_{I=1}^{N} P(I)$ would have to be changed with a 3 replacing the 2 and the time needed to fill a smaller tank would be less so R would no longer equal 121 when a manifold is used. The latter type of correction would become necessary when an unexpected minor delay is found to reoccur often in the hauling of a T pkg; then this delay must be added to the current value of U.

The control for the first possible group of errors is to review the model whenever the equipment design is changed and whenever more equipment is purchased. A comparison between the characteristics of the old equipment upon which the model is based and the new equipment will demonstrate whether the model must be changed or a task time duration must be changed or nothing be changed.

The control for the second possible group of errors that could arise and most likely will arise is to record the time that every task requires for completion, that is, to keep an accurate and detailed log of the deployments of ADAPTS. As each deployment is completed, the data generated by the deployment should be merged with data from prior deployments. Average values should be computed and compared against the model values. It is doubtful

that probability distributions will be derivable for these values since the equipment will evolve as experience is gained: the changes in the equipment may occur too rapidly for deployments with the same equipment to accumulate data to generate a probability distribution.

Uses for the Model

A prime use for the model is to determine the outcome of the deployment of a given set of resources to a distress that arises. Then the need for alternative measures can be determined. Should an incident arise in which it is required that a tanker to be emptied of its cargo and another tanker is available to receive all of it, this would be the preferred alternative. The possibility exists that ADAPTS would be needed for 10, 12, of 20 hours and then tankers would be available. The possible combinations are numerous. In many of them the model can be used directly, in others the model results must be interpreted. In some cases the model can be used to provide upper and lower bounds on what can be done. The model was used in such a manner for Volume 1 of this report.

Each equation is based upon 24 hours (1440 minutes) for results. By changing 1440 to another time, the investigator can compute results in 10, 12, 36, 48, etc. hours should these times be important. The model can be changed by replacing 1440 wherever it appears with TIME. This new variable can be read in initially and incremented in a DO loop to give results at regular intervals of time.

A final use of the model is to evaluate the effectiveness of an equipment change. By using the model in simulated distresses with and without a proposed

equipment change, the investigator can determine the effect of the proposed change and it can be evaluated along with the cost (among other factors) of the change.

APPENDIX A

```
C          ADAPTS MATHEMATICAL MODEL
           DIMENSION A(15),P(15),PMAX(15),NC(15)
           READ 900,NJOB
      900  FORMAT (I2)
           DO 2 K=1,NJOB
           PRINT 829,K
      829  FORMAT(1H1,15X,17H DATA SET NUMBER ,I2)
           READ 904,N,NCREW,CEND
      904  FORMAT(I2,I3,F5.2)
           IF(N.GE.1.AND.N.LE.15) GO TO 5
           PRINT 830
      830  FORMAT(15X,14H N WAS CHANGED)
           PRINT 807,N
      807  FORMAT(15X,4H N =,I5)
           N=15
           PRINT 807,N
        5  READ 901,(A(I),I=1,N)
           READ 901,(P(I),I=1,N)
      901  FORMAT (15F5.0)
           READ 902,DE,D1,D2,Q1,Q2,Q52,M1,M2,CHECK1
      902  FORMAT (6F5.0,2I5,F5.0)
           READ 903,L,S,D,E1,E2,E,R,U
      903  FORMAT (I5,7F10.0)
           B = D+(6.*DE/27.)+20.
           C = 6.*DE/29.
           H1 = 32.+D1/2.
           H2 = 32.+D2/2.
           H52 = 30.+2.*D1/3.
           KEY=0
           IF(CHECK1.EQ.0.) GO TO 98
           PRINT 800
      800  FORMAT(1H0,15X,13H DATA ERRORS=)
      C  PMAX(I) IS AN UPPER UPPER BOUND FOR P(I)
           DO 50 I=1,N
           PMAX(I)=(1440.-A(I))/(B+C)
           IF(PMAX(I).GE.P(I)) GO TO 50
           PRINT 801,I,P(I),I,PMAX(I)
      801  FORMAT(15X,3H P(,I2,3H) =,F10.5,6H PMAX(,I2,3H) =,F10.5)
       50  CONTINUE
      C HELICOPTERS ARE CONSTRAINED BY DISTANCE
           MH1=D1+10.
           MH2=MIN1(10.+(D1+D2)/2.,10.+D2)
           MH52=2*H52-50
           IF(MH1.GT.182) Q1=0.
           IF(MH2.GT.182) Q2=0.
           IF(MH52.GT.120) Q52=0.
           IF(Q1.NE.0.) Q52=0.
           IF(M1.LE.2) GO TO 51
           PRINT 802,M1
      802  FORMAT(15X,5H M1 =,I[illegible]IPMENT PACKAGES AT HP1)
           KEY=1
       51  IF(M2.LE.2) GO TO 52
           PRINT 803,M2
      803  FORMAT(15X,5H M2 =,I5,26H EQUIPMENT PACKAGES AT HP2)
```

```
      KEY=1
52    IF(Q1.LE.2.) GO TO 53
      PRINT 804,Q1
804   FORMAT(15X,5H Q1 =,F5.1,15H HH-3E*S AT HP1)
      KEY=1
53    IF(Q2.LE.1.) GO TO 54
      PRINT 805,Q2
805   FORMAT(15X,5H Q2 =,F5.1,15H HH-3E*S AT HP2)
      KEY=1
54    IF(Q52.LE.2.) GO TO 56
      PRINT 806,Q52
806   FORMAT(15X,6H Q52 =,F4.1,16H HH-52A*S AT HP1)
      KEY=1
56    IF(L.LE.N.AND.L.LE.15) GO TO 57
      PRINT 808,L,N
808   FORMAT(15X,4H L =,I5,16H LOADERS AND N =,I5,8H C-130*S)
      KEY=1
57    IF(L.GE.1) GO TO 58
      PRINT 809,L
809   FORMAT(15X,4H L =,I5)
      KEY=1
58    DO 59 I=2,N
      J=I-1
      IF(A(J).LE.A(I)) GO TO 59
      PRINT 810,J,A(J),I,A(I)
810   FORMAT(15X,3H A(,I2,3H) =,F5.1,4H, A(,I2,3H) =,F5.1)
      KEY=1
59    CONTINUE
      IF(Q1.NE.0..OR.Q52.NE.0.) GO TO 60
      PRINT 804,Q1
      PRINT 805,Q2
      PRINT 806,Q52
      KEY=1
60    IF(KEY.EQ.1) GO TO 999
      PRINT 811
811   FORMAT(1H+,29X,4HNONE)
98    SUMP=0.
      SUMAL=0.
      SUMAN=0.
      NCTEMP = NCREW
      DO 101 I=1,N
      NC(I) = 0
      SUMP=SUMP+P(I)
      SUMAN=SUMAN+A(I)
      IF(I.GT.L) GO TO 101
      SUMAL=SUMAN
101   CONTINUE
      RHO = (N*D)/((B+C)*L)
      IX1 = (AMIN1(1.,RHO))*((1440.-R-U-B+D)*L-SUMAL)/D
C     IX1 IS THE LOADER AND C130 CONSTRAINT EQUATION
      NUP=2*L
      IF(NUP.GT.N) NUP=N
C     ASSIGN CREWS TO AIRCRAFT
500   DO 501 II=1,NUP
```

```
            IF(NCTEMP.LE.0) GO TO 502
            NC(IT) = NC(IT)+1
      501   NCTEMP = NCTEMP-1
            IF(NCTEMP.GT.0) GO TO 500
      502   IX5 = 0
            EN = 60.*CEND
            TA = 1440.+C-B-U
            DO 503 IJ=1,NUP
            IF(IJ.GT.L) GO TO 504
            IX5=IX5+AMIN1(EN*NC(IJ),TA-A(IJ))/(B+C)
            GO TO 503
      504   IX5=IX5+AMIN1(EN*NC(IJ)-D,TA-D-A(IJ))/(B+C)
      503   CONTINUE
            IX5T = 2*IX5-SUMP
            IX2=0
            DO 600 I=1,N
      600   IX2=IX2+(TA-A(I))/(B+C)
      C   IX2 IS THE MAXIMUM NUMBER OF C130 TRIPS THAT CAN BE MADE IF
      C      EACH PLANE HAS A LOADER, IX2 IS NOT USED IN FINDING THE
      C        VALUE OF Z.    IT IS THE UPPER BOUND ON THE C130*S
      C   IX3T, THE MAXIMUM NUMBER OF BAGS THAT CAN BE FILLED BY
      C        PUMPS AT THE SCENE
      C   IX5 IS THE MAXIMUM NUMBER OF C130 TRIPS THAT CAN BE MADE DUE TO
      C        THE NUMBER OF C130*S, AIR CREWS, AND LOADERS
            IX2B=2*IX2-SUMP
            PRINT 827
      827   FORMAT(1H0,30X,24HUNCONSTRAINED C130 TRIPS)
            PRINT 825,IX2
      825   FORMAT(15X,7H IX2  =,I5,19H C130 TRIPS AT BEST)
            PRINT 831,IX2B
      831   FORMAT(15X,7H IX2B =,I5,30H BAGS FILLED IF NO CONSTRAINTS)
            EP = E2+H1
            EPKG2 = A(1)+B+EP
            EPKG1 = EPKG2+2.*H1
            EPKG3 = EP+F
            BAG1 = A(1)+B+U
            IX3T=0
            IF(M1.EQ.0.OR.Q1.EQ.0.) GO TO 200
            IX3T=MAX1(0.,(1440.-A(1)-B-E2-3.*H1)/R)
            IF(M1.NE.2) GO TO 200
            IF(Q1.EQ.1.) GO TO 201
            IX3T= IX3T+MAX1(0.,(1440.-AMAX1(EPKG3,AMAX1(EPKG2,BAG1)))/R)
            GO TO 200
      201   IX3T= IX3T+ MAX1(0.,(1440.-EPKG1-2.*S*H1)/R)
      200   IF(Q1.NE.0.) GO TO 300
            IF(Q52.EQ.0..OR.M1.EQ.0) GO TO 300
            EPKG4 = E2+F+11.*H52-4.*H52*Q52
            IX3T=IX3T+MAX1(0.,(1440.-AMAX1(EPKG4,BAG1))/R)
            IF(M1.NE.2) GO TO 300
            EPKG5 = E2+F+25.*H52-9.*H52*Q52+(3.-Q52)*S*H52
            IX3T=IX3T+MAX1(0.,(1440.-EPKG5)/R)
      300   IF(M2.EQ.0.OR.Q2.EQ.0.) GO TO 400
            EPKG6 = E2+F+H2
            IX3T=IX3T+MAX1(0.,(1440.-AMAX1(EPKG6,BAG1))/R)
```

```
          IF(M2.EQ.1) GO TO 400
          EPKG7 = EPKG6+2.*H2
          BAG2 = BAG1
          IF(P(1).NE.0.) BAG2=BAG2+B+C
          TBAG2=BAG2+1.
          IF(N.NE.1) TBAG2=A(2)+B+U
          IX3T=IX3T+MAX1(0.,(1440.-AMAX1(EPKG7,AMIN1(BAG2,TBAG2)))/R)
    400   DO 401 I=1,N
          IDUM =(1440.+C-E1-A(I)-(B+C)*(P(I)+1.)/2.)*P(I)/R
          IF(IDUM.GE.0) GO TO 401
          PRINT 812,I,IDUM
    812   FORMAT(15X,3H I=,I3,8H  IDUM =,I5)
          IDUM=0
    401   IX3T=IX3T+IDUM
C IX1T IS THE NUMBER OF BAGS THAT CAN BE FILLED DUE TO C-130 AND
C LOADER CONSTRAINTS.
C IX1 IS THE MAXIMUM NUMBER OF EFFECTIVE PLANE LOADS IN 24 HOURS.
C IX3T IS THE NUMBER OF BAGS THAT CAN BE FILLED DUE TO E PKG CONSTRAIN
C  Z IS THE MAXIMUM NUMBER OF BAGS THAT CAN BE FILLED IN 24 HOURS.
          IX1T=2*IX1-SUMP
C IX5T = MAX NUMBER BAGS THAT CAN BE FILLED DUE TO C130 CREW CONSTRAIN
          Z=AMIN0(IX1T,IX3T,IX5T)
          PRINT 826
    826   FORMAT(1H0,31X,13HINPUT VALUES=)
          PRINT 808,L,N
          PRINT 840,NCREW
    840   FORMAT(2H  ,11X,8H NCREW =,2X,I3,9H AIRCREWS)
          PRINT 841,CEND
    841   FORMAT(2H  ,11X,23H CREW ENDURANCE, CEND =,F5.2,6H HOURS)
          PRINT 842,EN
    842   FORMAT(2H  ,26X,3H OR,F10.2,8H MINUTES)
          PRINT 850
    850   FORMAT(1H0,14X,5HC-130,5X,7HSTANDBY,3X,6HNUMBER,4X,6HNUMBER)
          PRINT 851
    851   FORMAT(15X,6HNUMBER,5X,4HTIME,6X,4HCREW,6X,4HEPKG)
          PRINT 852
    852   FORMAT(17X,1HI,8X,4HA(I),6X,5HNC(I),5X,4HP(I))
          DO 853 IK=1,N
    853   PRINT 854,IK,A(IK),NC(IK),P(IK)
    854   FORMAT(16X,I2,8X,F5.0,6X,I2,6X,F5.0)
          PRINT 855
    855   FORMAT(1H0,17X,4HLOAD,6X,4HHELO,4X,7HPUMPING)
          PRINT 856
    856   FORMAT(18X,5HC-130,5X,5HSTDBY,5X,4HRATE)
          PRINT 857,D,F,R
    857   FORMAT(11X,3F10.0)
          PRINT 858
    858   FORMAT(1H0,18X,2HE1,8X,2HE2,8X,1HU)
          PRINT 857,E1,E2,U
          PRINT 802,M1
          PRINT 803,M2
          PRINT 804,Q1
          PRINT 805,Q2
          PRINT 806,QS2
```

```
      PRINT 813,DF
  813 FORMAT(15X,5H DF =,F10.2,25H MILES FROM ECAS TO SCENE)
      PRINT 814,D1
  814 FORMAT(15X,5H D1 =,F10.2,24H MILES FROM HP1 TO SCENE)
      PRINT 815,D2
  815 FORMAT(15X,5H D2 =,F10.2,24H MILES FROM HP2 TO SCENE)
      PRINT 816,S
  816 FORMAT(15X,5H S  =,F10.2,23H SALVAGE TEAMS OF 4 MEN)
      PRINT 817,SUMP
  817 FORMAT(15X,7H SUMP =,F8.2,23H C-130 DELIVERED E PKGS)
      PRINT 828
  828 FORMAT(1H0,31X,7HOUTPUT=)
      PRINT 819,RHO
  819 FORMAT(15X,42H AVERAGE FACILITY USAGE FOR LOADERS,RHO  =,F10.2)
      PRINT 820,BAG1
  820 FORMAT(15X,42H FIRST BAG READY FOR CONNECTING AT BAG1  =,F10.2)
      PRINT 818,IX1
  818 FORMAT(15X,44H C130 TRIPS MAX:C130,LDR CONSTRAINTS,IX1 =  ,I5)
      PRINT 843,IX5
  843 FORMAT(15X,44H C130 TRIPS MAX:AIR CREW CONSTRAINT, IX5 =  ,I5)
      PRINT 844,IX5T
  844 FORMAT(15X,44H 24 HR BAG MAX:AIR CREW CONSTRAINT, IX5T =  ,I5)
      PRINT 821,IX1T
  821 FORMAT(15X,44H 24 HR BAG MAX:C130,LDR CONSTRAINTS,IX1T =  ,I5)
      PRINT 822,IX3T
  822 FORMAT(15X,44H 24 HR BAG MAX:PUMP,HELO CONSTRAINTS,IX3T=  ,I5)
      PRINT 823,Z
  823 FORMAT(1H0,18X,38HTHE MAXIMUM NUMBER OF BAGS FILLED,Z  =,F10.0)
      GO TO 2
  999 PRINT 824
  824 FORMAT(15X,12H RUN ABORTED)
    2 CONTINUE
      STOP
        END
```

APPENDIX B

GLOSSARY

A(I) Standby of the Ith C-130. It includes air crew and aircraft standby, rail installation time, time required to notify the air station, and the time to start response. A(I) is defined in the order the C-130's become available; hence, $A(1) \leq A(2) \leq A(I) \leq A(I+1) \leq A(N)$.

ADAPTS The acronym used for the Air Deliverable Anti-Pollution Transfer System. It is described in chapter 1.

B The time required to load a C-130, fly it to the scene and drop a load of two packages. Loading time includes fueling time for the C-130. B = D+20+60*DE/270

C The time required to fly the C-130 back for the scene to ECAS. C = 60*DE/290

CEND The allowable flight time for C-130 air crews, the Crew ENDurance.

CHECK1 A keying variable used to call for input data checks; a value of 1.0 calls for the checking.

D The time required to load a C-130, standardized at 90 minutes using a 25K loader and 120 minutes using a makeshift loader.

DE The distance from ECAS to the scene in nautical miles

D1 The distance from HP1 to the scene in nautical miles.

D2 The distance from HP2 to the scene in nautical miles.

E1 The set up time for a C-130 delivered E pkg, it is the lapsed time from the completion of the drop to the time the pump is ready for use. It is standardized at 75 minutes.

E2 The set up time for a hel[illegible] delivered E pkg, it is the lapsed time

from the unloading of the helicopter to the time the pump is ready for use. It is standardized at 20 minutes.

ECAS Elizabeth City Air Station in North Carolina. The only Coast Guard Air Station on the East Coast equipped with C-130's.

E pkg The package of equipment used in the ADAPTS system to pump oil into the folding tanks. It is packaged for dropping from a C-130 or for delivery by a helicopter and it includes an HLD, pump, prime mover, and fuel.

F The standby time of 1st helicopter. It includes air crew and helicopter standby, sling installation, loading time, and the time required to notify the Coast Guard and to start response.

H1 A standardized helicopter trip time for HP1 using HH-3F's. The average of 30+10+60*D1/115 and 30+60*D1/125 where the loading, refueling, unloading, time to fly to scene, and the returning from the scene are all included.

H1 = 32+D1/2 minutes

H2 A standardized helicopter trip time for HP2 using HH-3F's.

H2 = 32+D2/2 minutes; it is the one way trip time.

H52 A standardized helicopter trip time for HP1 using HH-52A's.

H52 = 30+2*D1/3 minutes; it is the one way trip time.

HLD The acronym for the A frame used in ADAPTS. It is used to haul in the E pkgs and the T pkgs; it has a manual winch and tie down lines.

HP1 The symbol used to designate the Coast Guard Air Station nearest to the scene of distress from which helicopter are flown.

HP2 The symbol used to designate the next nearest air station from which helicopters are flown to the scene of distress.

Incident See Pollution Incident.

IX1T The number of tanks that can be filled in 24 hours due to C-130 and

C-130 loader constraints. IX1 is the corresponding number of C-130 trips.

IX2 The maximum number of plane loads that can be delivered due to the number of C-130's without regard to other constraints.

IX3T The number of tanks that can be filled in 24 hours by the pumps constrained by the method of delivery and the number of helicopters.

IX5T The number of tanks that can be filled due to C-130, C-130 loader, and C-130 air crew constraints. IX5 is the corresponding number of C-130 trips in 24 hours.

M1 The number of E pkgs at HP1. M1 = 0,1,2

M2 The number of E pkgs at HP2. M2 = 0,1,2

N The number of C-130's.

NC(I) The number of air crews assigned to the Ith 1-30.

NCREW The number of air crews available to fly C-130's.

NJOB The number of data decks being run in the FORTRAN model.

P(I) The number of E pkgs delivered by the Ith C-130.

Pollution Incident The imminent threat of a spill or a spill of such magnitude or significance as to require immediate response to contain, cleanup or dispose of the material (oil) to prevent a substantial threat to public health or welfare including finfish, shellfish, or other wildlife and shorelines and beaches.

Potential Spill Any accident or other circumstance which threatens to result in the discharge of oil or other hazardous substance. A potential spill can be classified as minor, moderate, or major.

Q1 The number of HH3F's at HP1. Q1 = 0,1,2

Q2 The number of HH3F's at HP2. Q2 = 0,1

Q52 The number of HH52A's at H11. Q52 = 0,1, 2

R The tank filling rate, standardized at 120 minutes filling time plus hookup time. It equals 121 minutes if manifolds are available and it equals 144 minutes if no manifolds are available.

Rho or RHO The Facility Utilization Factor for the C-130 loaders.

S The number of four man salvage teams.

SUMP The total number of E pkgs delivered by C-130's.

$$SUMP = \sum_{I=1}^{N} P(I)$$

T pkg The package designed for air dropping from a C-130 containing a folded rubber tank of 500 tons of oil capacity. It also contains hose and an anchor. The tank is sometimes referred to as a bag.

U The time lapse between the entry of the T pkg into the water and the time that the hose end is at the distressed tanker. It is standardized at 40 minutes when using an HLDl and at 12 minutes when using a helicopter tow to bring the hose end to the tanker. These times are based upon a distance of 100 yards from the anchored tank to the distressed tanker.

Z* The maximum number of tanks that can be filled in 24 hours.

APPENDIX C

SAMPLE ADAPTS PROBLEM

```
DATA SET NUMBER  3

DATA ERRORS= NONE

                     UNCONSTRAINED C130 TRIPS
IX2  =   24 C130 TRIPS AT BEST
IX2B =   46 BAGS FILLED IF NO CONSTRAINTS

                      INPUT VALUES=
L =     2 LOADERS AND N =      3 C-130*S
NCREW =     3 AIRCREWS
CREW ENDURANCE, CEND =12.00 HOURS
                 OR    720.00 MINUTES

C-130       STANDBY    NUMBER      NUMBER
NUMBER       TIME       CREW        FPKG
  I          A(I)       NC(I)       P(I)
  1           13.         1          1.
  2           88.         1          1.
  3           88.         1          0.

  LOAD        HELO     PUMPING
  C-130       STDBY      RATE
  90.         43.        121.

   E1          E2         U
  80.         20.        40.
M1 =     2 EQUIPMENT PACKAGES AT HP1
M2 =     2 EQUIPMENT PACKAGES AT HP2
Q1 =  2.0 HH-3F*S AT HP1
Q2 =  1.0 HH-3F*S AT HP2
Q52 = 0.0 HH-52A*S AT HP1
DE =      85.00 MILES FROM ECAS TO SCENE
D1 =      85.00 MILES FROM HP1 TO SCENE
D2 =      85.00 MILES FROM HP2 TO SCENE
S  =       6.00 SALVAGE TEAMS OF 4 MEN
SUMP =     2.00 C-130 DELIVERED F PKGS

                      OUTPUT=
AVERAGE FACILITY USAGE FOR LOADERS,RHO  =       0.92
FIRST BAG READY FOR CONNECTING AT BAG1  =     181.89
C130 TRIPS MAX:C130,LDR CONSTRAINTS,IX1 =      24
C130 TRIPS MAX:AIR CREW CONSTRAINT, IX5 =      12
24 HR BAG MAX:AIR CREW CONSTRAINT, IX5T =      22
24 HR BAG MAX;C130,LDR CONSTRAINTS,IX1T =      46
24 HR BAG MAX:PUMP,HELO CONSTRAINTS,IX3T=      55

   THE MAXIMUM [illegible] BAGS FILLED,Z  =         22.
```

APPENDIX D

FORMAT FOR INPUT OF DATA

Data is entered into the FORTRAN model in sets preceeded by a single card with the variable NJOB on it (format statement 900). NJOB is the number of data sets being investigated during the current computer run of the model.

Each data deck consists of five cards using format statements:

Card	Format Statement	Numbers on Card
1	904	N, NCREW, CEND
2	901	A(I), I = I, N
3	901	P(I), I = 1, N
4	902	DE, D1, D2, Q1, Q2, Q52, M1, M2, CHECK1
5	903	L, S, D, E1, E2, F, R, U